

**TITLE: SPECIFICATION BASED DETECTION AND REPAIR OF  
ERRORS IN DATA STRUCTURES**

Inventors: Brian C. Demsky, et al.

Filed: November 26, 2003 MIS-00401

Agent: Anne E. Saturnelli Reg. No.: 41,290

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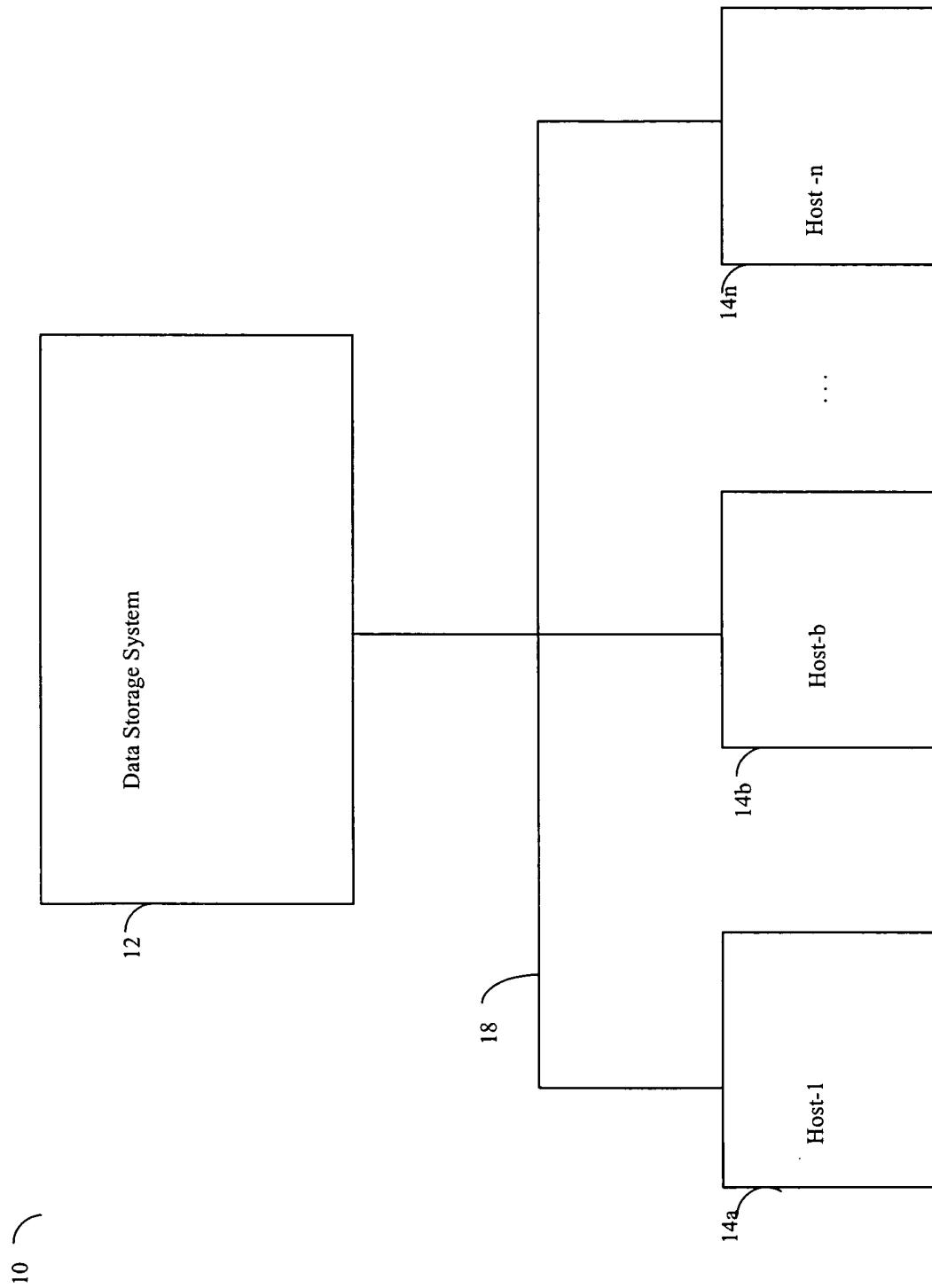


FIGURE 1

**TITLE: SPECIFICATION BASED DETECTION AND REPAIR OF  
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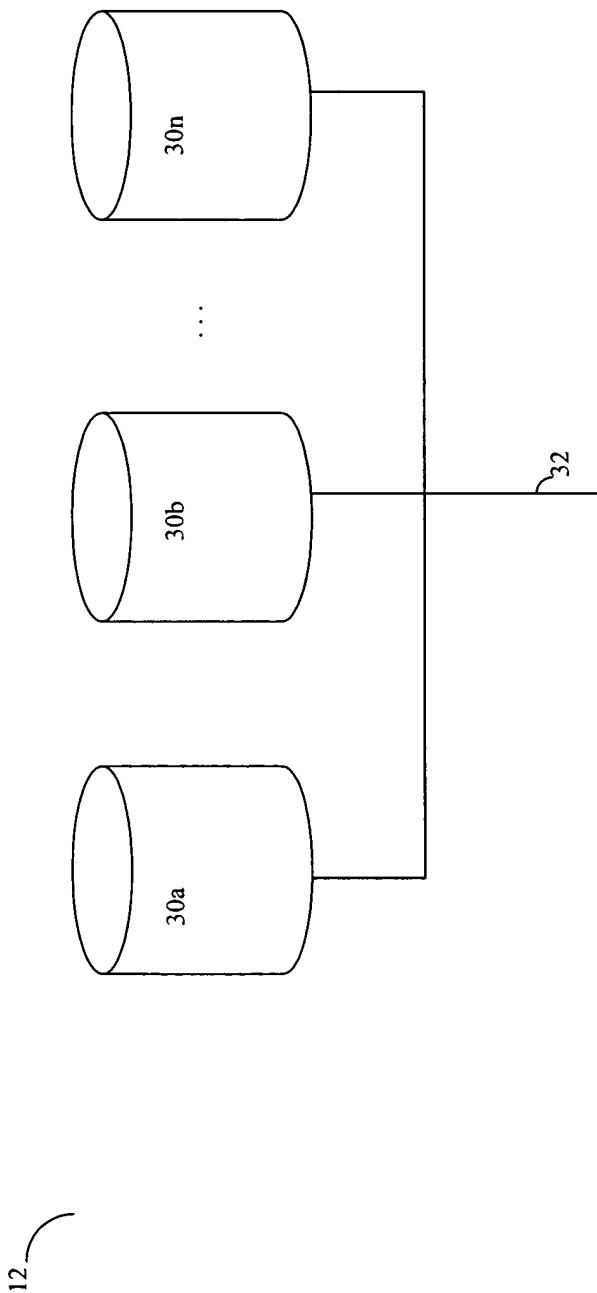


FIGURE 2

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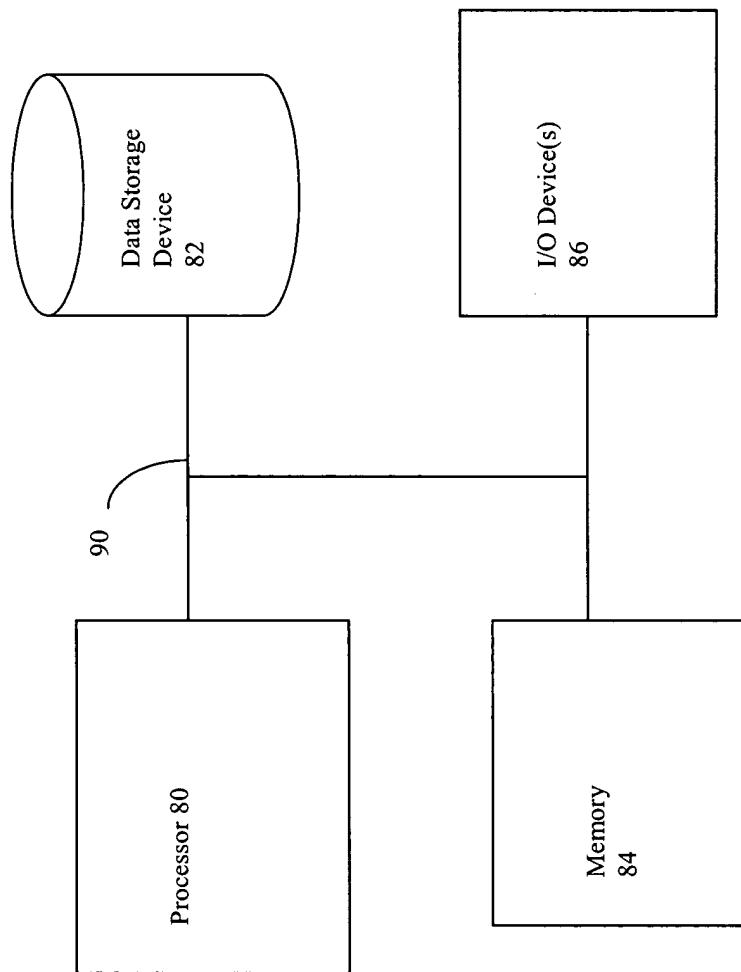
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**FIGURE 3**

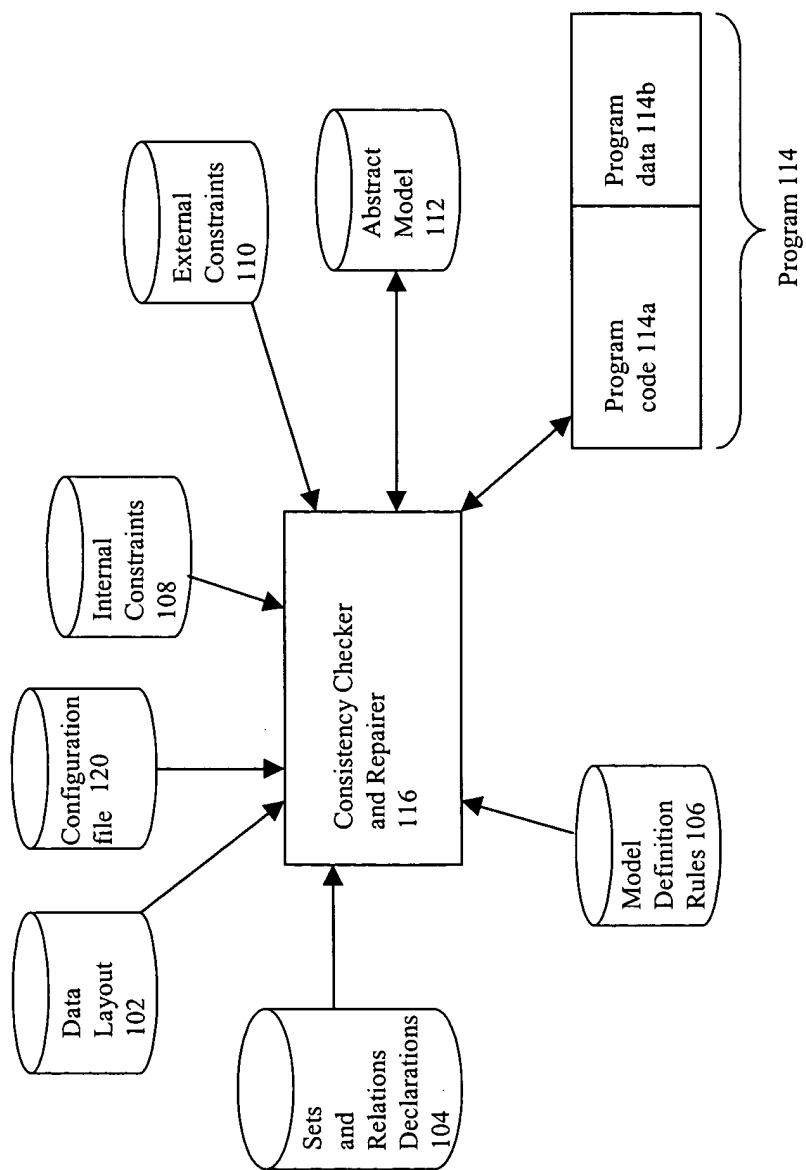
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**FIGURE 4**

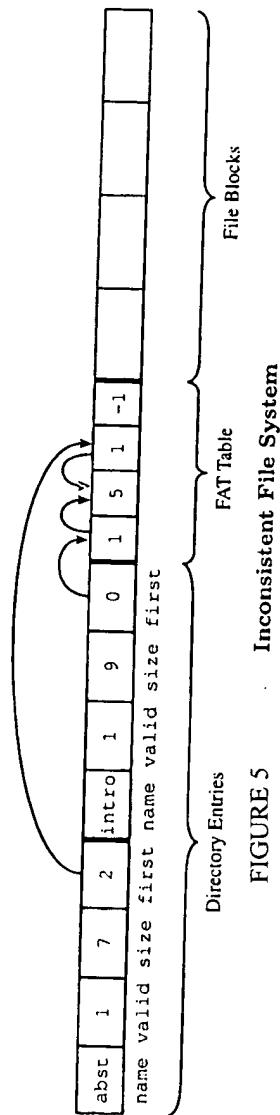
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**FIGURE 5      Inconsistent File System**

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```
structdefn  :=  struct structurename
                  (subtypes structurename) {fielddefn*}

fielddefn  :=  type field; | reserved type; |
                  type field[E]; |
                  reserved type[E];

type      :=  boolean | byte | short | int | structurename |
                  structurename *

E         :=  V | number | string | E.field |
                  E.field[E] | E - E | E + E | E/E | E * E
```

**FIGURE 6**      **Structure Definition Language**

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```
124
struct Entry {
    byte name[Length];
    byte valid;
    int size;
    int first;
}

struct Block {
    data byte[BlockSize];
}

struct Disk {
    Entry table[NumEntries];
    int FAT[NumBlocks];
    Block block[NumBlocks];
}
```

**FIGURE 7 . Structure Declarations**

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125 {  
set S of T : Partition  $S_1, \dots, S_n$   
relation R :  $S_1 \rightarrow S_n$

FIGURE 8A

126 {  
set blocks of integer : partition used | free  
relation next : used  $\rightarrow$  used;

FIGURE 8B

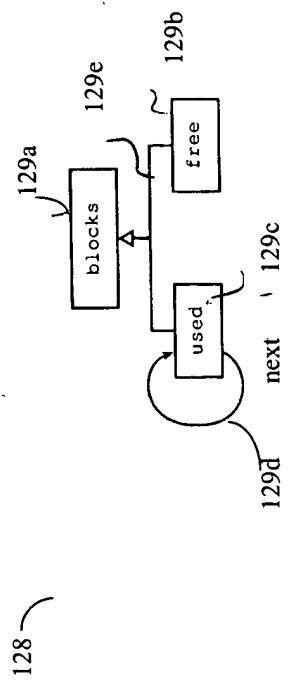
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**FIGURE 9** Graphical Representation of Object and Relation Declarations

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```
C  :=  Q, C | G ⇒ I
Q  :=  for V in S | for ⟨V, V⟩ in R |
      for V = E .. E
G  :=  G and G | G or G | G | E = E | E < E | true |
      (G) | E in S | ⟨E, E⟩ in R
I  :=  E in S | ⟨E, E⟩ in R
E  :=  V | number | string | E.field |
      E.field[E] | E - E | E + E | E/E | E * E
```

FIGURE 10 Model Definition Language

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$hv \in \text{HeapValue} = \text{Bit} \cup \text{Byte} \cup \text{Short} \cup \text{Integer} \cup \text{Struct}$   
 $h \in \text{Heap} = \mathcal{P}(\text{Object} \times \text{Field} \times \text{HeapValue} \cup \text{Object} \times \text{Field} \times \mathbb{N} \times \text{HeapValue})$   
 $v \in \text{Value} = \mathbb{Z} \cup \text{Boolean} \cup \text{string} \cup \text{Struct}$   
 $l \in \text{Local} = \text{Var} \rightarrow \text{Value}$   
 $s \in \text{Store} = \text{Value} \times \text{Value} \cup \text{Value}$   
 $m \in \text{Model} = \mathcal{P}(\text{Var} \times \text{Store})$   
 $\mathcal{R} : C \rightarrow \text{Heap} \rightarrow \text{Local} \rightarrow \text{Model} \rightarrow \text{Model}$   
 $\mathcal{E} : E \rightarrow \text{Heap} \rightarrow \text{Local} \rightarrow \text{Model} \rightarrow \text{Value}$   
 $\mathcal{G} : G \rightarrow \text{Heap} \rightarrow \text{Local} \rightarrow \text{Model} \rightarrow \text{Boolean}$   
 $\mathcal{I} : I \rightarrow \text{Heap} \rightarrow \text{Local} \rightarrow \text{Model} \rightarrow \text{Model}$

$\mathcal{R}[\text{for } V \text{ in } S, C] h l m = \bigcup_{u \in m(S)} \mathcal{R}[C] h l[V \mapsto v] m$   
 $\mathcal{R}[\text{for } (V_1, V_2) \text{ in } R, C] h l m = \bigcup_{(v_1, v_2) \in m(R)} \mathcal{R}[C] h l[V_1 \mapsto v_1][V_2 \mapsto v_2] m$   
 $\mathcal{R}[\text{for } V = E_1 \text{ in } E_2, C] h l m =$   
 $\bigcup_{i \in \mathcal{E}[E_2] h l m} \mathcal{R}[C] h l[V \mapsto i] m$   
 $\mathcal{R}[C \Rightarrow I] h l m = \text{if } (\mathcal{G}[C] h l m) \text{ then } (\mathcal{I}[I] h l m) \text{ else } m$   
 $\mathcal{G}[G_1 \text{ and } G_2] h l m = (\mathcal{G}[G_1] h l m) \wedge (\mathcal{G}[G_2] h l m)$   
 $\mathcal{G}[G_1 \text{ or } G_2] h l m = (\mathcal{G}[G_1] h l m) \vee (\mathcal{G}[G_2] h l m)$   
 $\mathcal{G}[\neg G] h l m = \neg(\mathcal{G}[G] h l m)$   
 $\mathcal{G}[E_1 = E_2] h l m = (\mathcal{E}[E_1] h l m) == (\mathcal{E}[E_2] h l m)$   
 $\mathcal{G}[E_1 < E_2] h l m = (\mathcal{E}[E_1] h l m) < (\mathcal{E}[E_2] h l m)$   
 $\mathcal{G}[\text{true}] h l m = \text{true}$   
 $\mathcal{G}[E \text{ in } S] h l m = \langle S, \mathcal{E}[E] h l m \rangle \in m$   
 $\mathcal{G}(E_1, E_2) \text{ in } R] h l m = \langle R, \mathcal{E}[E_1] h l m, \mathcal{E}[E_2] h l m \rangle \in m$   
 $\mathcal{I}[E \text{ in } S] h l m = m \cup (S, \mathcal{E}[E] h l m)$   
 $\mathcal{I}(E_1, E_2) \text{ in } R] h l m = m \cup \langle R, (\mathcal{E}[E_1] h l m, \mathcal{E}[E_2] h l m) \rangle$   
 $\mathcal{E}[\vee] h l m = \iota(\vee)$   
 $\mathcal{E}[\text{number}] h l m = \text{number}$   
 $\mathcal{E}[E, \text{field}] h l m = b \text{ such that } ((\mathcal{E}[E] h l m), \text{field}, b) \in h$   
 $\mathcal{E}[E_1, \text{field}(E_2)] h l m =$   
 $\text{c, such that } ((\mathcal{E}[E_1] h l m), \text{field}, (\mathcal{E}[E_2] h l m), \text{c}) \in h$   
 $\mathcal{E}[E_1 \oplus E_2] h l m = \text{primop}(\oplus, (\mathcal{E}[E_1] h l m), (\mathcal{E}[E_2] h l m))$   
 $\mathcal{E}[\text{string}] h l m = \text{string}$

**FIGURE 11 Denotational Semantics for Model Definition Language**

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Disk disk;  
  
for i in 0..NumEntries, disk.table[i].valid **&&**  
disk.table[i].first < NumBlocks =>  
disk.table[i].first in used;  
for b in used, 0 <= disk.FAT[b] **&&**  
disk.FAT[b] < NumBlocks => disk.FAT[b] in used;  
for b in used, 0 <= disk.FAT[b] **&&**  
disk.FAT[b] < NumBlocks =>  
<b,disk.FAT[b]> in next;  
for b in 0..NumBlocks, !(b in used) => b in free;

FIGURE 12A Model Definition Declarations and Rules

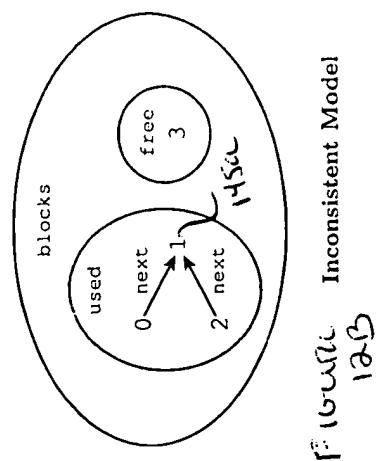
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$C := Q, C \mid B$   
 $Q := \text{for } V \text{ in } S \mid \text{for } V = E .. E$   
 $B := B \text{ and } B \mid B \text{ or } B \mid B \mid (B)$   
 $VE = E \mid VE < E \mid VE <= E \mid VE > E \mid$   
 $VE >= E \mid V \text{ in } SE \mid \text{size}(SE) = C \mid$   
 $\text{size}(SE) >= C \mid \text{size}(SE) <= C$   
 $VE := V.R$   
 $E := V \mid \text{number} \mid \text{string} \mid E + E \mid E - E \mid E/E \mid$   
 $E * E \mid E.R \mid \text{size}(SE) \mid (E)$   
 $SE := S \mid V.R \mid R.V$

Fig. 13 Internal Constraint Language

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$v \in Value = Number \cup Boolean \cup string \cup Object$   
 $l \in Local = \mathcal{P}(Var \times Value)$   
 $m \in Model = \mathcal{P}(Var \times Store)$   
 $s \in Store = Value \times Value \cup Value$   
 $\mathcal{E}V : C \rightarrow Local \rightarrow Model \rightarrow Boolean$   
 $\mathcal{E} : E \rightarrow Local \rightarrow Model \rightarrow Value$   
 $C : B \rightarrow Local \rightarrow Model \rightarrow Boolean$   
 $V : VE \rightarrow Local \rightarrow Model \rightarrow Value$   
 $SE : SE \rightarrow Local \rightarrow Model \rightarrow \mathcal{P}(Value)$

$\mathcal{E}V[for\ V\ in\ S.\ C]\ l\ m =$   
 $\lambda_{V\in m(S)}\ \mathcal{E}V[C]\ l[V \mapsto v]\ m$   
 $\mathcal{E}V[for\ V = E_1..E_2, C]\ l\ m =$   
 $\lambda_{E_1..E_2\in m}\ \mathcal{E}V[C]\ l[V \mapsto v]\ m$   
 $\lambda_{E\in E_1..E_2\in m}\ \mathcal{E}V[C]\ l[V \mapsto v]\ m$   
 $\mathcal{E}V[B]\ l\ m = C[B]\ l\ m$   
 $C[B]\ l\ m = \neg C[B]\ l\ m$   
 $C[B_1] \text{ and } B_2\ l\ m = C[B_1]\ l\ m \wedge C[B_2]\ l\ m$   
 $C[B_1] \text{ or } B_2\ l\ m = C[B_1]\ l\ m \vee C[B_2]\ l\ m$   
 $C[V\ in\ SE]\ l\ m = l(V) \in SE\ l\ m$   
 $C[V\ E\ =\ E]\ l\ m = (V[V\ E])\ l\ m == \mathcal{E}[E]\ l\ m$   
 $C[V\ E\ <\ E]\ l\ m = (V[V\ E])\ l\ m < \mathcal{E}[E]\ l\ m$   
 $C[V\ E\ <= E]\ l\ m = (V[V\ E])\ l\ m \leq \mathcal{E}[E]\ l\ m$   
 $C[V\ E\ >\ E]\ l\ m = (V[V\ E])\ l\ m > \mathcal{E}[E]\ l\ m$   
 $C[V\ E\ >= E]\ l\ m = (V[V\ E])\ l\ m \geq \mathcal{E}[E]\ l\ m$   
 $C[\text{size}(SE) = C]\ l\ m = \mathcal{E}[\text{size}(SE)]\ l\ m == C$   
 $C[\text{size}(SE) >= C]\ l\ m = \mathcal{E}[\text{size}(SE)]\ l\ m \geq C$   
 $C[\text{size}(SE) <= C]\ l\ m = \mathcal{E}[\text{size}(SE)]\ l\ m \leq C$   
 $V[V, R]\ l\ m = y \text{ such that } \langle (V, y), y \rangle \in m(R)$   
 $\mathcal{E}[\text{size}(SE)]\ l\ m = |\mathcal{E}[SE]\ l\ m|$   
 $\mathcal{E}[V]\ l\ m = l(V)$   
 $\mathcal{E}[E, R]\ l\ m = y \text{ such that } \exists z, z \in \mathcal{E}[E]\ l\ m \wedge \langle z, y \rangle \in m(R)$   
 $\mathcal{E}[E_1 \oplus E_2]\ l\ m = \text{primon}(\oplus, \mathcal{E}[E_1]\ l\ m, \mathcal{E}[E_2]\ l\ m)$   
 $SE[S]\ l\ m = \{s \mid s \in m(S)\}$   
 $SE[V, R]\ l\ m = \{y \mid \langle (V, y), y \rangle \in m(R)\}$   
 $SE[R, V]\ l\ m = \{y \mid \langle y, (V) \rangle \in m(R)\}$

$\mathcal{E}V$   $\mathcal{E}$  Denotational Semantics for Internal Constraint Language

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$R ::= Q, R \mid G \Rightarrow C$   
 $Q ::= \text{for } V \text{ in } S \mid \text{for } \langle V, V \rangle \text{ in } R \mid \text{for } V = E \dots E$   
 $G ::= G \text{ and } G \mid G \text{ or } G \mid G \mid G \mid E = E \mid E < E \mid \text{true}$   
 $C ::= HE.field = E \mid HE.field[E] = E \mid V = E$   
 $HE ::= V \mid HE.field \mid HE.field[E]$   
 $E ::= V \mid \text{number} \mid \text{string} \mid E.R \mid E - E \mid E + E \mid$   
 $E * E \mid E/E \mid \text{size}(SE) \mid \text{element } E \text{ of } SE$   
 $SE ::= S \mid V.R \mid R.V$

*Figure 15* External Constraint Language

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$hv \in \text{HeapValue} = \text{Bit} \cup \text{Byte} \cup \text{Short} \cup \text{Integer} \cup \text{Struct}$   
 $h \in \text{Heap} = \mathcal{P}(\text{Object} \times \text{Field} \times \text{HeapValue} \cup$   
 $v \in \text{Value} = \mathbb{Z} \cup \text{Boolean} \cup \text{string} \cup \text{Struct}$   
 $l \in \text{Local} = \text{Var} \rightarrow \text{Value}$   
 $s \in \text{Store} = \text{Value} \times \text{Value} \cup \text{Value}$   
 $m \in \text{Model} = (P)(\text{Var} \times \text{Store})$   
 $\mathcal{R} : R \rightarrow \text{Heap} \rightarrow \text{Local} \rightarrow \text{Model} \rightarrow \text{Boolean}$   
 $\mathcal{E} : E \rightarrow \text{Heap} \rightarrow \text{Local} \rightarrow \text{Model} \rightarrow \text{Value}$   
 $\mathcal{HE} : HE \rightarrow \text{Heap} \rightarrow \text{Local} \rightarrow \text{Model} \rightarrow \text{Object}$   
 $\mathcal{G} : G \rightarrow \text{Heap} \rightarrow \text{Local} \rightarrow \text{Model} \rightarrow \text{Boolean}$   
 $\mathcal{C} : C \rightarrow \text{Heap} \rightarrow \text{Local} \rightarrow \text{Model} \rightarrow \text{Boolean}$   
 $\mathcal{SE} : SE \rightarrow \text{Local} \rightarrow \text{Model} \rightarrow \text{Value}$

$\mathcal{R}[\text{for } V \text{ in } S, R]h l m = \bigwedge_{v \in m(S)} \mathcal{R}[R]h l [V \mapsto v]m$   
 $\mathcal{R}[\text{for } (V_1, V_2) \text{ in } R, R]h l m = \bigwedge_{(v_1, v_2) \in m(R)} \mathcal{R}[R]h l [V_1 \mapsto v_1, V_2 \mapsto v_2]m$   
 $\mathcal{R}[R]h l [V_1 \mapsto v_1][V_2 \mapsto v_2]m = \mathcal{E}[E_2]h l m$   
 $\mathcal{R}[R]h l [V \mapsto v]m = \bigwedge_{v \in \mathcal{E}[E_1]h l m}$   
 $\mathcal{R}[C] \Rightarrow C[h l m = (\neg G[C])h l m) \vee C[C]h l m)$   
 $G[G_1 \text{ and } G_2]h l m = (G[G_1]h l m) \wedge (G[G_2]h l m)$   
 $G[G_1 \text{ or } G_2]h l m = (G[G_1]h l m) \vee (G[G_2]h l m)$   
 $G[G_1]h l m = \neg(G[G_1]h l m)$   
 $G[E_1 < E_2]h l m = (\mathcal{E}[E_1]h l m) \mathbin{==} (\mathcal{E}[E_2]h l m)$   
 $G[\text{true}]h l m = \text{true}$   
 $C[HE, \text{field} = E]h l m = (\mathcal{HE}[HE]h l m, \text{field}, \mathcal{E}[E]h l m) \in h$   
 $C[HE, \text{field}[E_1] = E_2]h l m =$   
 $(\mathcal{HE}[HE]h l m, \text{field}, \mathcal{E}[E_1]h l m, \mathcal{E}[E_2]h l m) \in h$   
 $C[V = E]h l m = (V == \mathcal{E}[E]h l m)$   
 $\mathcal{HE}[HE, \text{field}[E]]h l m = b \text{ such that } (\mathcal{HE}[HE]h l m, field, b) \in h$   
 $\mathcal{HE}[HE, \text{field}[E]]h l m =$   
 $b \text{ such that } (\mathcal{HE}[HE]h l m, field, \mathcal{E}[E]h l m, b) \in h$   
 $\mathcal{E}[V]h l m = \mathcal{U}(V)$   
 $\mathcal{E}[\text{number}]h l m = \text{number}$   
 $\mathcal{E}[V, R]h l m = b \text{ such that } (V, b) \in \mathcal{E}^{m(R)}$   
 $\mathcal{E}[E_1 \oplus E_2]h l m = \text{primop}(\oplus, (\mathcal{E}[E_1]h l m), (\mathcal{E}[E_2]h l m))$   
 $\mathcal{E}[\text{string}]h l m = \text{string}$   
 $\mathcal{E}[\text{size}(SE)]h l m = |\mathcal{SE}[SE]h l m|$   
 $\mathcal{E}[\text{element } E \text{ of } SE]h l m = \text{given some ordering of } \mathcal{SE}[SE]h l m$   
 $\mathcal{SE}[S]h l m = \{s \mid s \in m(S)\}$   
 $\mathcal{SE}[V, R]h l m = \{y \mid \langle \langle V, y \rangle, y \rangle \in R\}$   
 $\mathcal{SE}[R, V]h l m = \{y \mid \langle y, \langle l(V) \rangle \rangle \in R\}$

**F (Formal Logic Denotational Semantics for External  
Constraint Language)**

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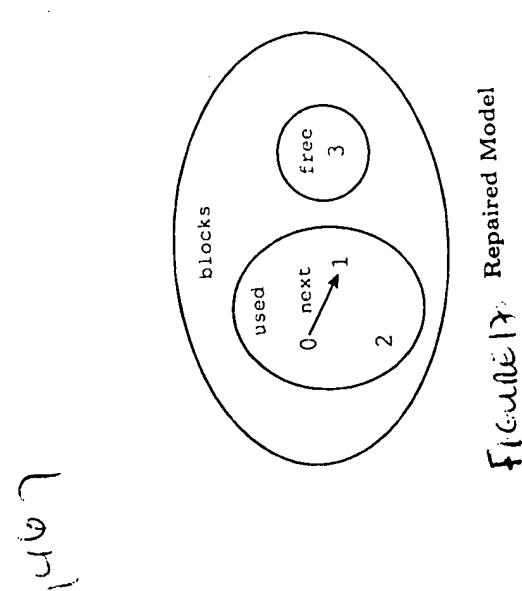


Figure 17. Repaired Model

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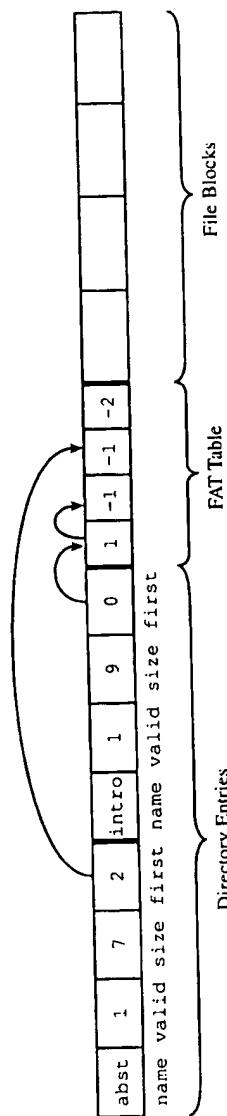


Figure 18 Repaired File System

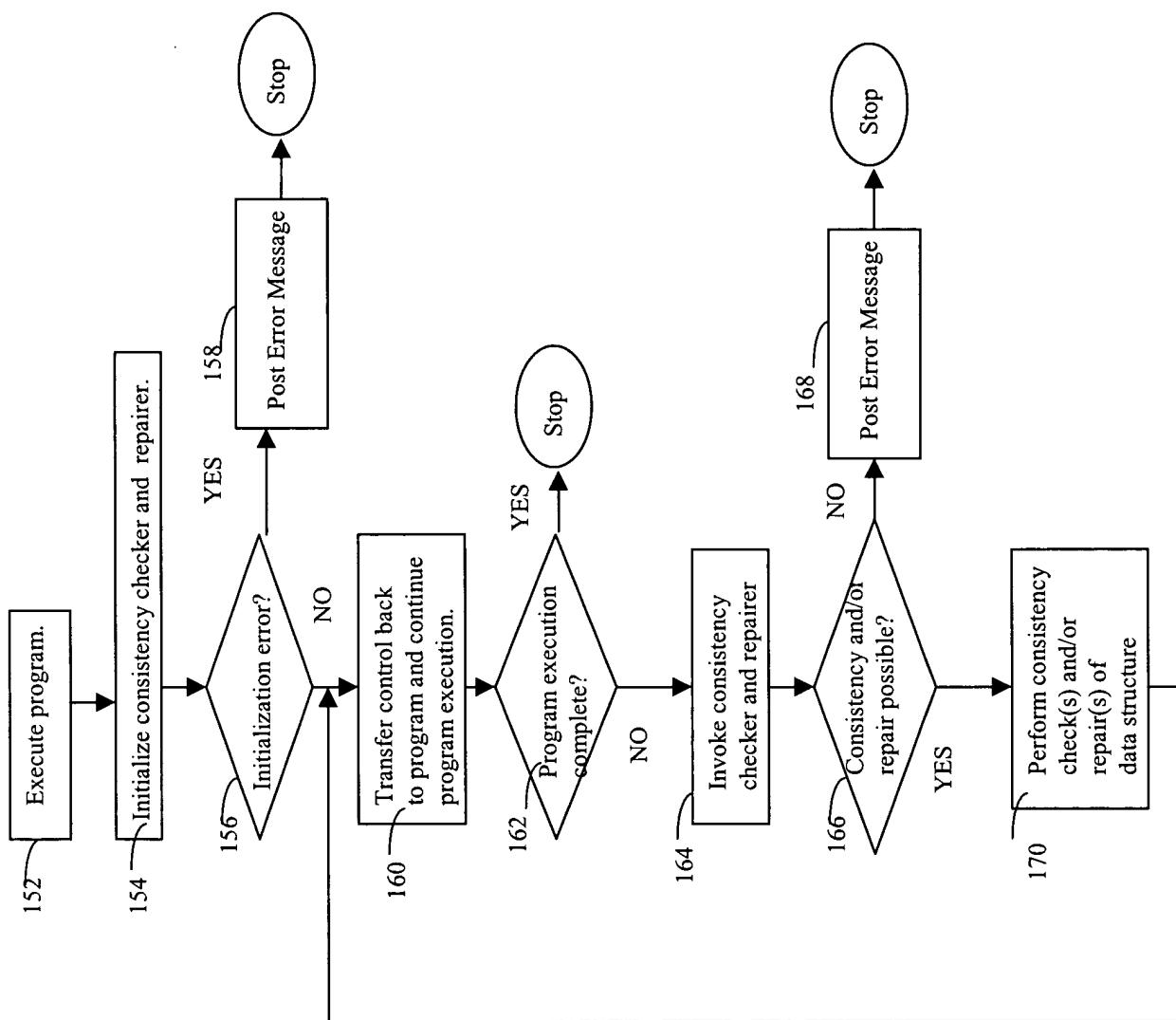
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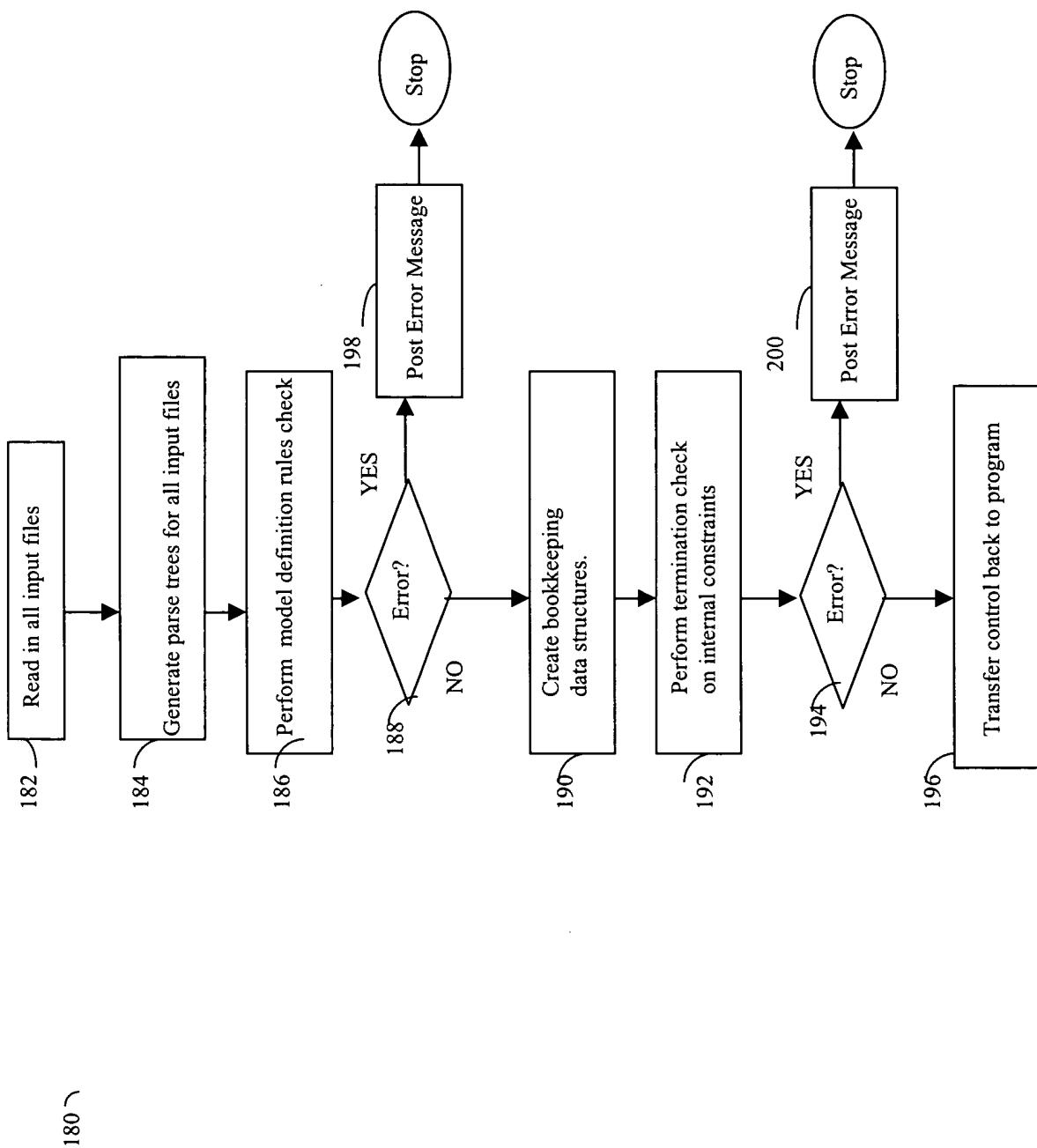


FIGURE 20

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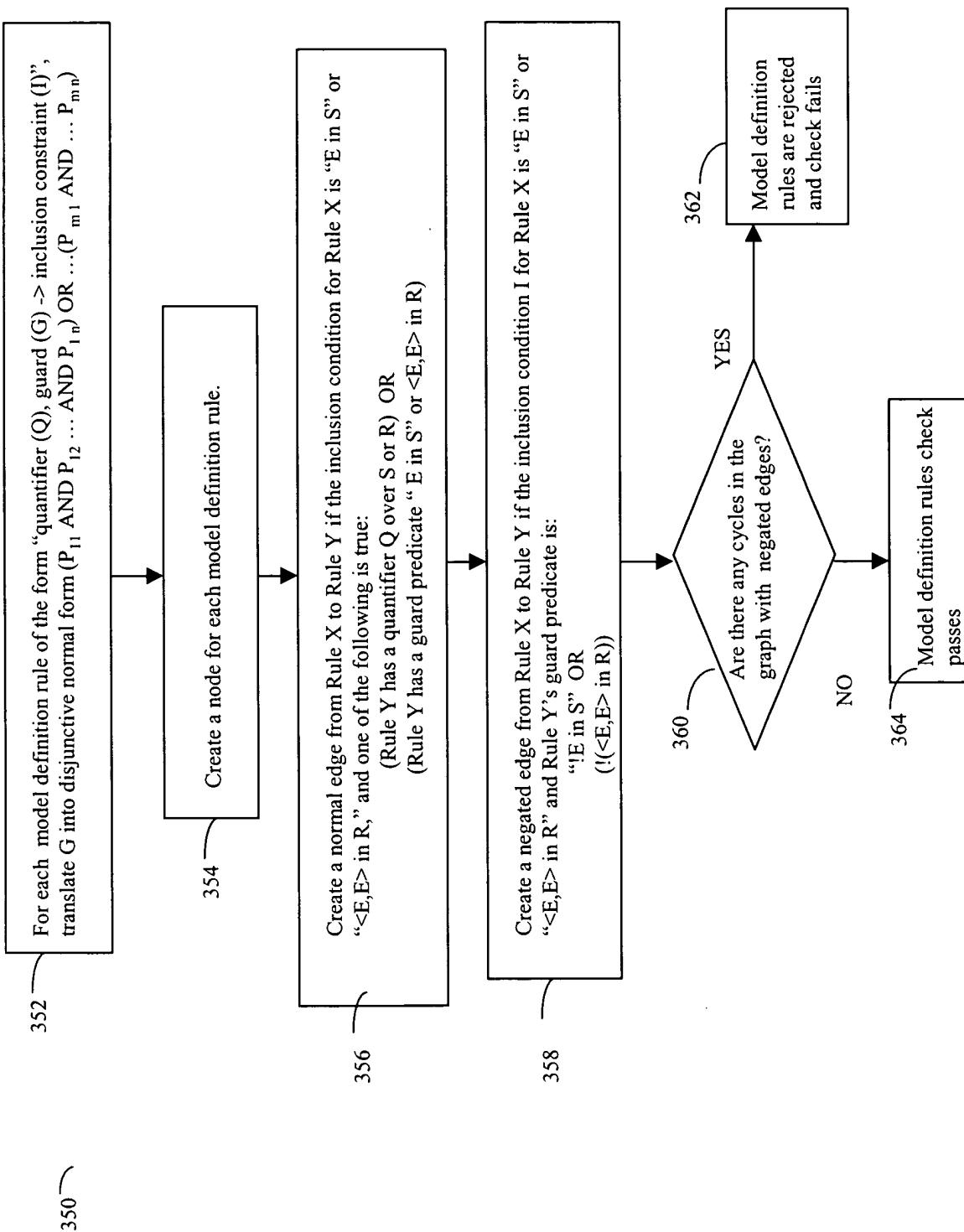


FIGURE 21

**TITLE: SPECIFICATION BASED DETECTION AND REPAIR OF  
ERRORS IN DATA STRUCTURES**

Inventors: Brian C. Demsky, et al.

Filed: November 26, 2003 MIS-00401

Agent: Anne E. Saturnelli Reg. No.: 41,290

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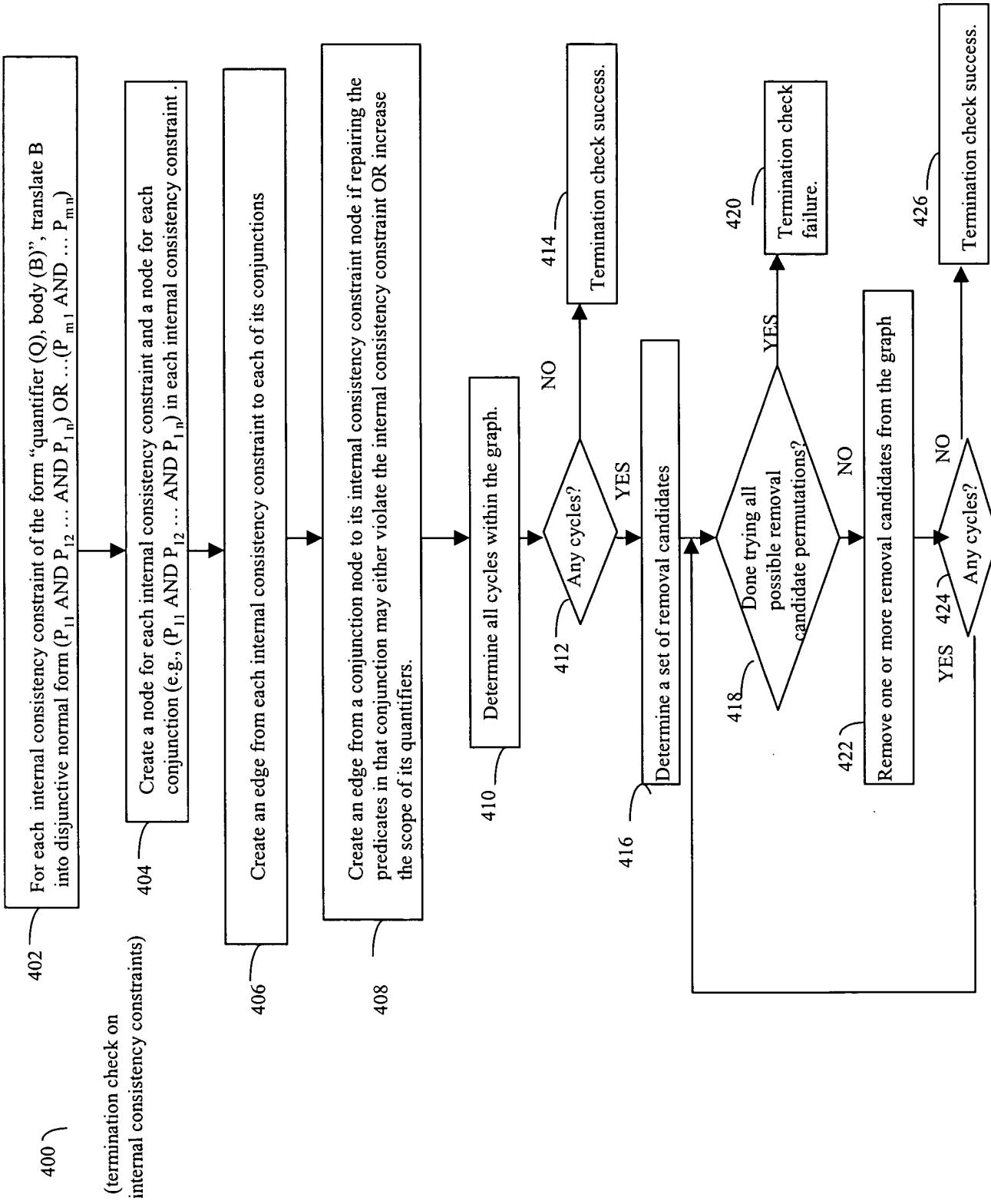


FIGURE 22

**TITLE: SPECIFICATION BASED DETECTION AND REPAIR OF  
ERRORS IN DATA STRUCTURES**

Inventors: Brian C. Demsky, et al.

Filed: November 26, 2003 MIS-00401

Agent: Anne E. Saturnelli Reg. No.: 41,290

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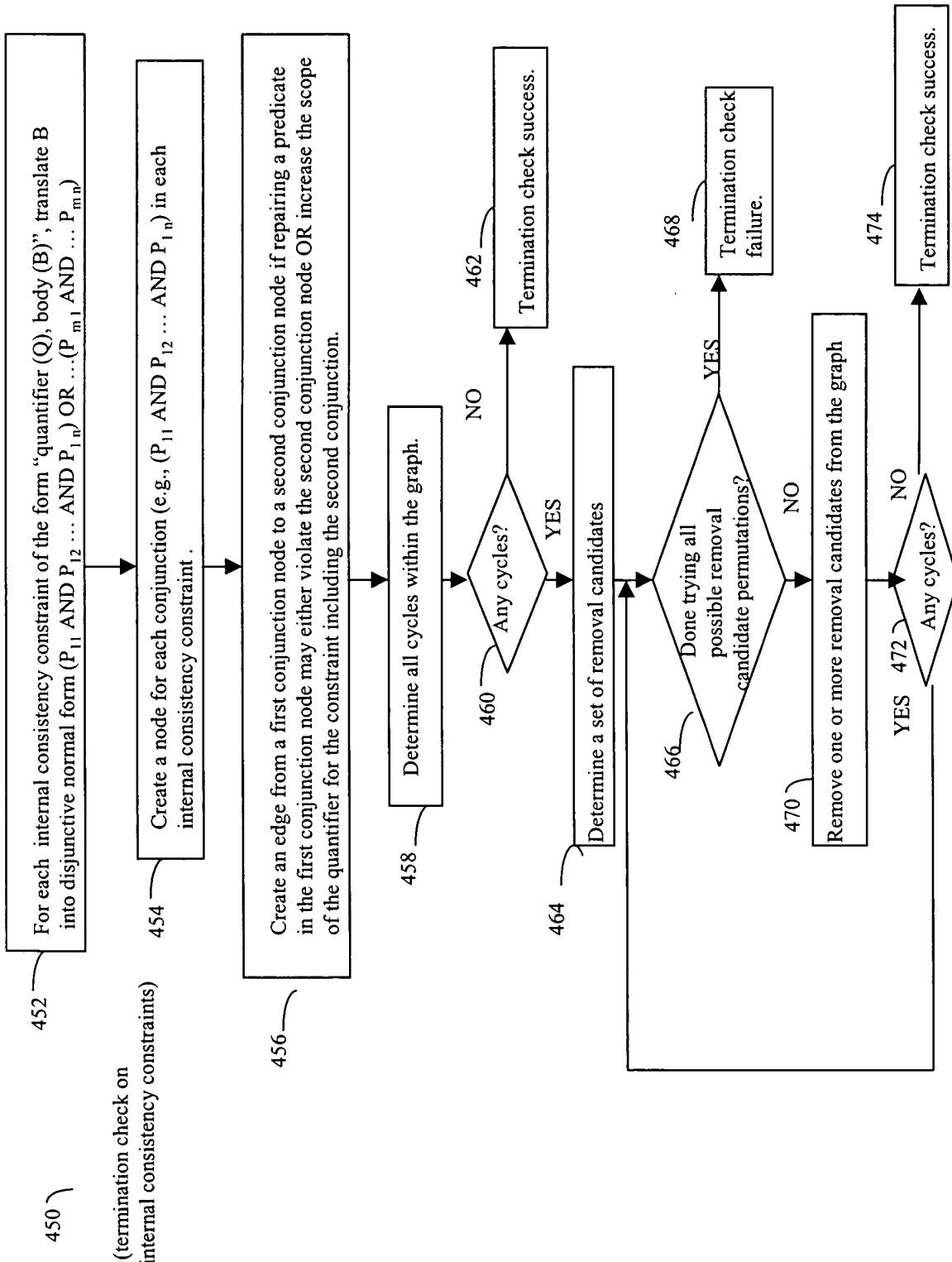


FIGURE 23

**TITLE: SPECIFICATION BASED DETECTION AND REPAIR OF  
ERRORS IN DATA STRUCTURES**

Inventors: Brian C. Demsky, et al.

Filed: November 26, 2003

MIS-00401

Agent: Anne E. Saturnelli

Reg. No.: 41,290

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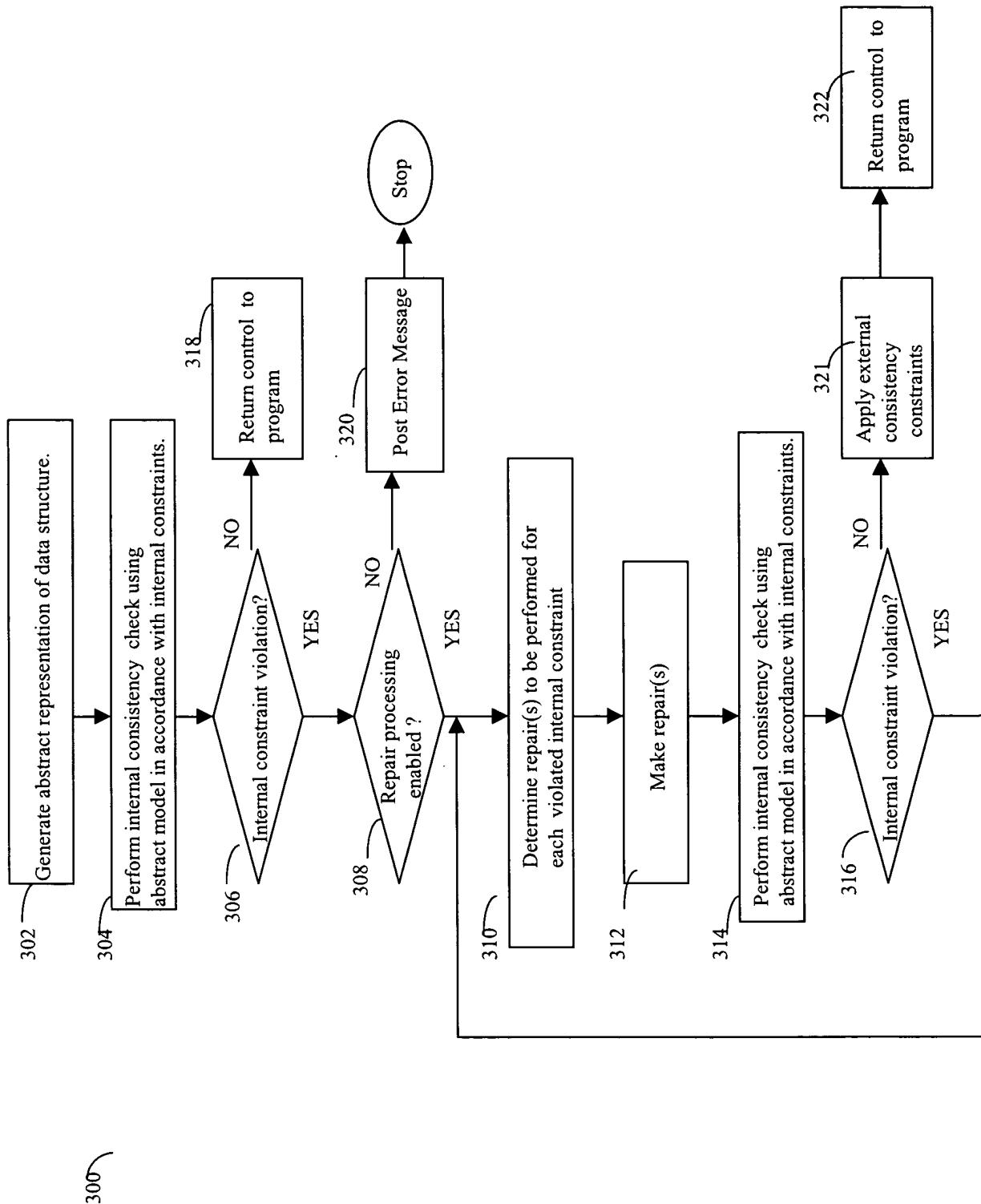


FIGURE 24

**TITLE: SPECIFICATION BASED DETECTION AND REPAIR OF  
ERRORS IN DATA STRUCTURES**

Inventors: Brian C. Demsky, et al.

Filed: November 26, 2003 MIS-00401

Agent: Anne E. Saturnelli Reg. No.: 41,290

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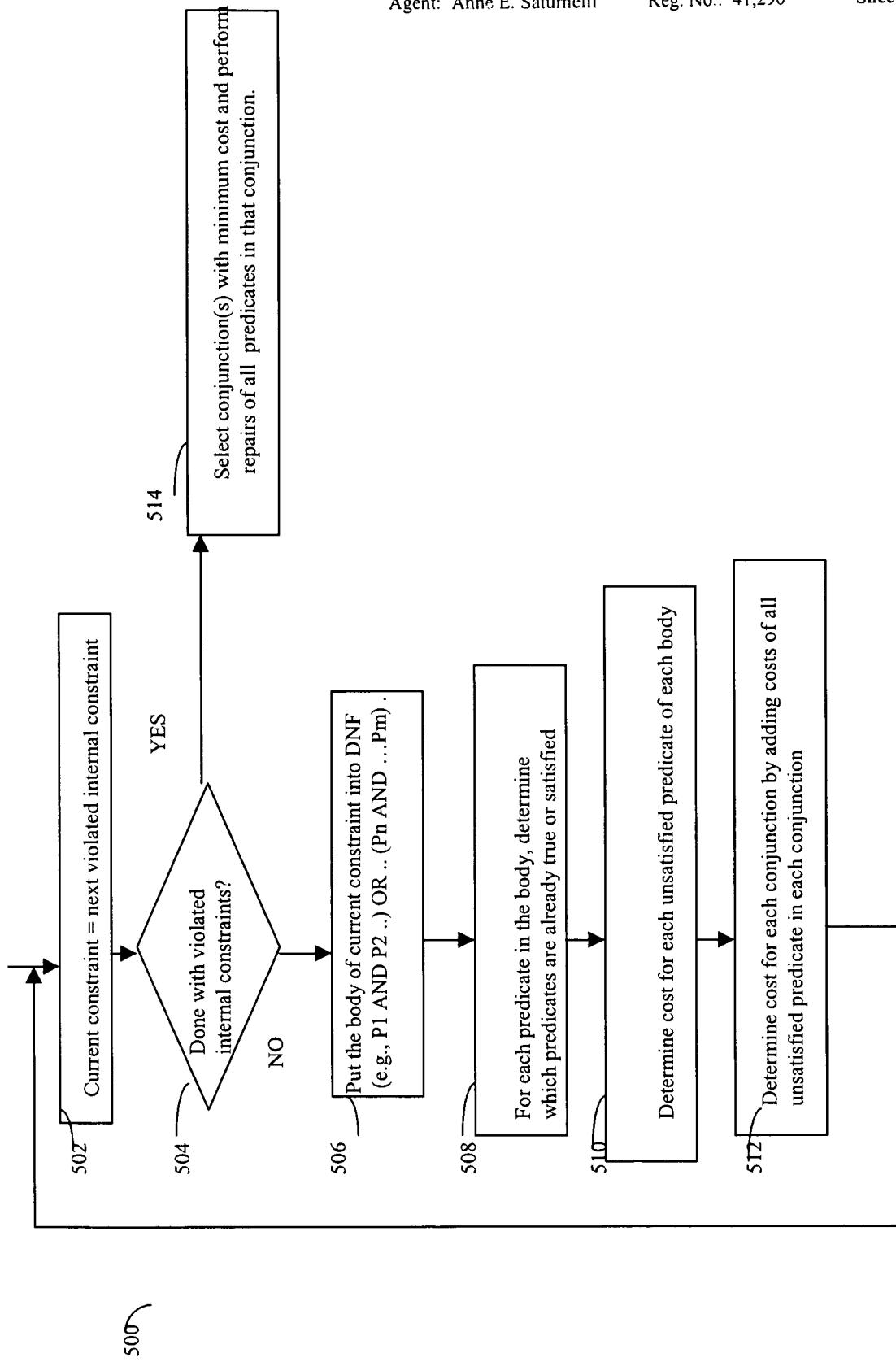


FIGURE 25

**TITLE: SPECIFICATION BASED DETECTION AND REPAIR OF  
ERRORS IN DATA STRUCTURES**

Inventors: Brian C. Demsky, et al.

Filed: November 26, 2003 MIS-00401

Agent: Anne E. Saturnelli Reg. No.: 41,290

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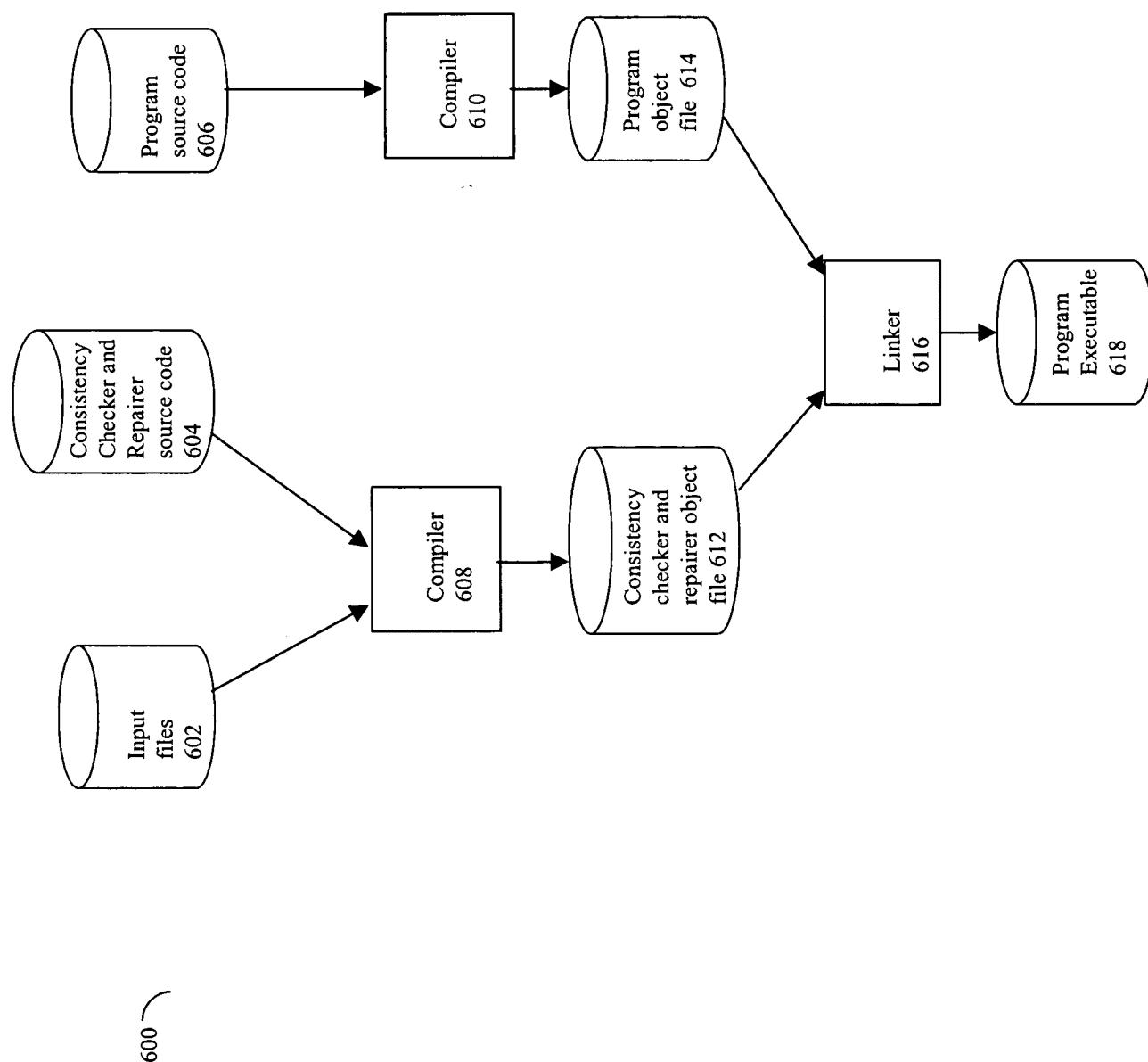


FIGURE 26

**TITLE: SPECIFICATION BASED DETECTION AND REPAIR OF  
ERRORS IN DATA STRUCTURES**

Inventors: Brian C. Demsky, et al.

Filed: November 26, 2003

MIS-00401

Agent: Anne E. Saturnelli

Reg. No.: 41,290

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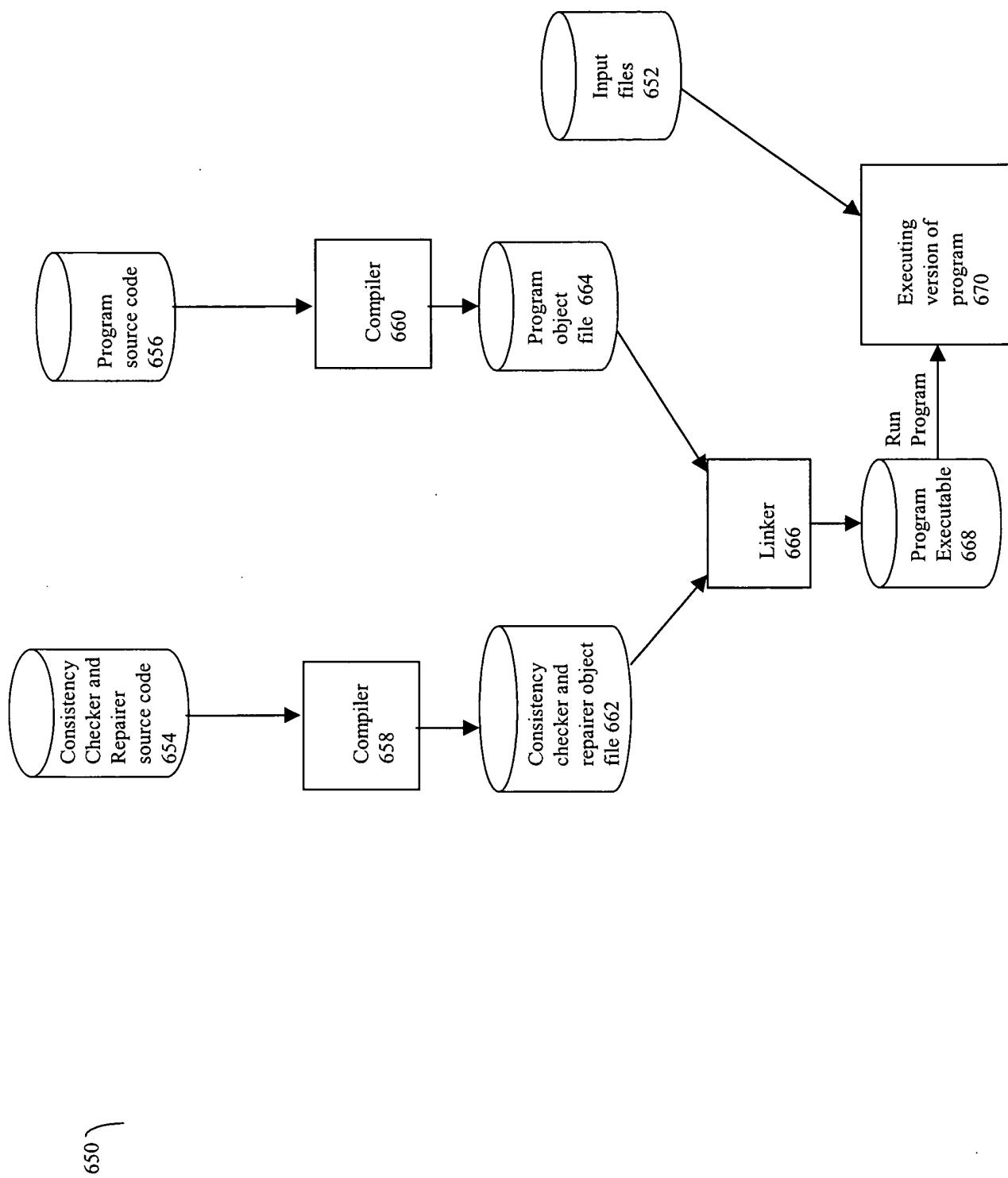


FIGURE 27